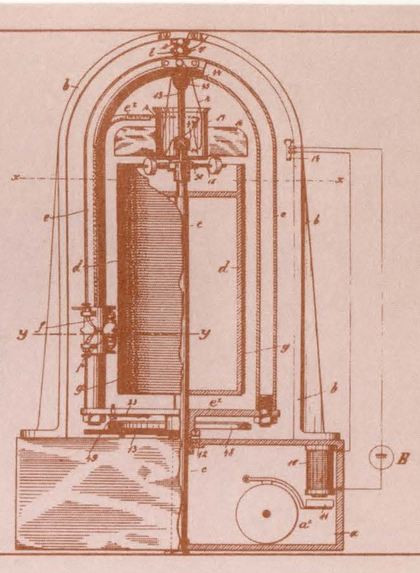
INSTRUMENTATION TECHNICAL INFORMATION NUMBER 6



SPECIFYING PHASE RESPONSE AND ENVELOPE DELAY IN AN INSTRUMENTATION TAPE RECORDER

AMPEX

With the introduction of wider bandwidth instrumentation recorders (the 1.5-MHz FR-1400 in 1962, and the 2.0-MHz FR-1600 in 1965), phase response, a frequently neglected performance characteristic, has assumed some importance in specifying recorder performance. Since the function of a recorder in recording and reproducing data is analogous to the transfer function of a communications network, several related terms from communications system analysis have come into common usage: envelope delay, group delay, phase linearity, transmission delay, phase distortion and time delay. The most meaningful of these is envelope delay. The question is, how does envelope delay affect certain types of data (AM, FM, sinusoidal, non-sinusoidal, multiplexed) when recorded and reproduced on a magnetic recorder. First, let's define some terms and see how they can be measured. (For more detail and mathematical derivations, see the references cited.)

Constant Time Delay

In an idealized network (and in certain recorder systems with specially designed delay lines and low pass filters) a constant time delay as shown in Figure 1 can be approached. With Direct recording, the characteristic is much closer to the curve in Figure 2, which is frequently referred to as *linear phase response*, to indicate the areas between A and B on the plot.

Envelope Delay

The best overall definition of phase response available today is envelope delay. This is the time delay (transmission delay) of the *modulation envelope* of an amplitude modulated signal when passed through a network. It is the first derivative of the phase shift, ϕ, with respect to frequency, ω, and is therefore the slope of the phase curve at the frequency of interest. In FM recording this term is usually called group delay (since no amplitude modulation envelope is produced in FM), although actual values measured on either AM or FM signals can be mathematically proven equal. An interesting fact about envelope delay is buried in the mathematics of definition and the modulation theory involved. The slope of the phase/frequency curve at a particular point, determines the envelope delay. This means there is no fixed relationship between the actual time delay of two sets of carrier and sideband groups and the envelope delay of the modulation. Signals at "a" and "b" of Figure 2 have identical slopes of phase/frequency curves and therefore equal envelope delay. Yet, the time delays of signals at these two frequencies are unequal. Conversely, signals at "c" and "d" in Figure 3 have unequal slopes of the phase/frequency curve and yet have equal time delays through the network. The important thing to remember is that *envelope delay refers only to a modulated signal, not to the absolute time delay of the carrier or sideband group involved*. Envelope delay distortion occurs when the rate of change of phase shift with frequency is not constant within the passband.

Measuring Phase Delay and Envelope Delay

Measurement of phase delay by itself is greatly complicated by the mechanics of tape recording. In any phase measurement, timing accuracy is an all-important parameter. A tape recorder translates time into mechanical motion. The static delay caused by the finite distance between the record and reproduce head is several orders of magnitude larger than the delay variations to be measured. In addition, there is a dynamic variation caused by any time base instability and flutter of the tape transport which is also much larger than the delay variation. When this is taken into account, previous methods which attempt to measure the phase delay by subtracting recorder delay from the figures obtained were, at best inaccurate.

The best method of measuring phase response, in terms of accuracy and repeatability, is envelope delay. It is measured by using a reference signal on the recorded track to which all delay values are compared. This technique is used in the envelope delay measurement apparatus (developed by Wandel and Goltermann) which has been adopted as the envelope delay measurement standard by IRIG in Telemetry Standard 106-66.

Practical Use of These Measurements

How to specify phase response depends to a great extent on the types of signals to be recorded. As a general rule, only a constant delay response will handle all signal types equally well.

AM Signals

Envelope delay measurement is the best way to specify phase response for AM signals. A recorder channel with no envelope delay variation over the frequency range of the AM carrier and its associated sidebands will introduce no distortion from this cause.

FM Signals

Again, envelope delay (group delay) is the pertinent criterion as this is exactly the type of signal it was intended to evaluate.

Sinusoidal Signals

With linearly mixed sinusoidal signals, the time relationship will be altered by the tape recorder in direct proportion to the degree of departure of the recorder channel from a constant time delay characteristic. Unfortunately, there is no easy way to determine this due to the large time delay introduced by the tape recording process. Additional complications in determining delay result if the signals are not harmonically related, as no convenient reference point exists for the measurement. Some test equipment has been built to measure this parameter on non-harmonic sinusoidal signals, but it is quite complex and not generally available.

Pulse and Other Non-Sinusoidal Waveforms

A non-linear signal such as a square wave or repetitive pulse train can be thought of to consist of a series of sinusoidal signals with a given frequency, amplitude and phase relationship. Each of these frequency components will be displaced in time in proportion to the amount of deviation of the delay curve of the recorder from a constant delay filter characteristic. If the particular waveform has all its required components confined to that section of the recorder bandpass exhibiting a constant time delay phase/frequency slope, no distortion of the pulse shape will occur. If distortion does occur (and if the signal has relatively few important frequency components outside the linear portion), some equalization can be performed on the recorder to improve the waveform response to this particular waveshape. Up to the present, it has proved impossible to construct a Direct recording system for a magnetic tape recorder with a constant time delay response over the entire reproduced frequency range. This is the primary reason for the poor square wave performance of the recorder. The lower frequency portion of the signal spectrum has a phase/frequency plot resembling the curved area in Figure 2. If the fundamental frequency of the square wave is close to the frequency of this "head bump" (caused by head faceplate-to-tape contact effects), the low frequency components of the square wave will be significantly shifted in phase in relation to the other frequency components. This results in an apparent sag or tilt in the flat top of the square wave. As the frequency of the wave is increased, the phase response of the recorder is generally improved, and pulse will become less distorted.

Multiplex Signals

If a large number of signals are multiplexed on the same tape track, such as a constant bandwidth FM multiplex group, the group delay of the tape recorder channel provides one measure of the time coincidence of the various channels of data. Here constant group delay, not constant time delay is important. In practice, however, the problems involved in the manufacture of filter sets for the constant bandwidth channel groups are of much greater magnitude than the group delay of the tape recorder involved. In the final analysis, both delays are of a static nature and can be eliminated completely with small trimming delay lines, so they create only a small problem in data reduction.

Conclusion

Measurement and specification of the phase and time delay response of a tape recorder is necessary for some types of signals. The most commonly quoted specification, envelope delay, is best for certain modulated signals such as AM, wideband FM and multiplex FM channel groups. In non-linear signal recording constant time delay characteristics are of much greater importance. Determine type of signal to be handled before choosing a phase response specification.

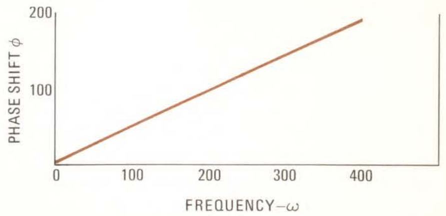


Figure 1. Constant time delay (1.4 msec) for an idealized network.

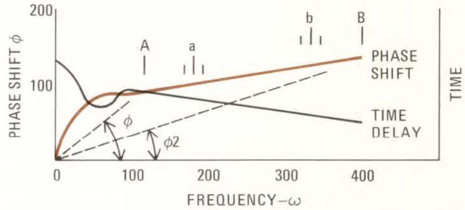


Figure 2. Phase shift curve, closely resembling response of a magnetic recorder. Note linear portion between A and B. Second curve shows related time delay for this phase shift curve.

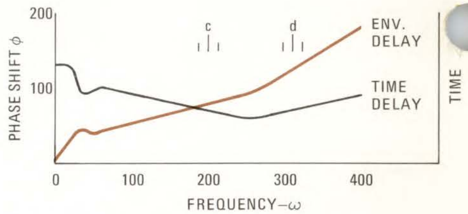


Figure 3. Typical envelope delay curve. Second curve shows related time delay.

For further study and mathematical derivations, the following are recommended:

1. Star, J., Ampex Corp., *Envelope Delay in a Tape Recorder System.* International Telemetry Conference Proceedings 1965, Vol. I, pp. 595-612.
2. Nyquist, H. and Brand, S., *Measurement of Phase Distortion.* Bell System Technical Journal, pp. 522-549, 1930.
3. De Boer, H.J. and Van Weel, A., *An Instrument for Measuring Group Delay.* Phillips Technical Review, pp. 315-316, Vol. 15 No. 11, May, 1954.
4. Cannon, W.D., *Delay Distortion Correction.* Transactions AIEE, Vol. 75, Communications and Electronics No. 23, pp. 56-61, March 1965.

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The drawing pictured on the front page is of the first magnetic recorder—the Telegraphone. The inventor, Valdemar Poulsen, received a U.S. patent approval for his "device for effecting the storing up of speech or signals by magnetically influencing magnetizable bodies" on November 13, 1900.

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